Epidemiology & Health Data Insights
(eISSN 3080-8111)

Review Article

HIV Care and Treatment Among Serodiscordant Couples: A Systematic Review of Relationship Dynamics and Health Outcomes

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Received: Jul 22, 2025
Accepted: Sep 13, 2025

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Abstract:

Background: Serodiscordant couples are relationships where one sexual partner is HIV-positive and the other is HIV-negative. Such couples experience complex relational and psychosocial challenges that significantly influence treatment adherence and health outcomes. Despite biomedical advances such as Antiretroviral Therapy (ART) and Pre-Exposure Prophylaxis (PrEP), the relational dynamics within these relationships remain underexplored in HIV intervention strategies.

Objective: To systematically review how HIV status disclosure and partner reactions impact treatment outcomes among serodiscordant couples.

Method: A systematic review of qualitative and mixed-methods studies published between 2010 and 2025 was conducted using databases including PubMed, PsycINFO, CINAHL, Scopus, and Google Scholar. Studies were appraised using the Critical Appraisal Skills Programme (CASP) Qualitative Checklist, and thematic synthesis was employed to analyze findings.

Findings and Discussion: Ninety four studies met the inclusion criteria. Key themes included HIV status disclosure, communication, partner reactions, partner support and impact on treatment adherence. Challenges such as stigma and fear of rejection hindered disclosure and engagement in care in some relationships. However, support from partners was key in boosting confidence and continuity in care.

Conclusion: HIV status disclosure is a crucial public health issue, as it has significant impact on the trajectory of serodiscordant relationships, treatment outcomes and psychosocial wellbeing of PLHIV. Building culturally sensitive, couple-centered interventions that emphasizes increased HIV awareness and knowledge is essential for improving health outcomes among serodiscordant couples.

Keywords: People Living with HIV (PLHIV); Serodiscordant couples; HIV Status Disclosure; Partner support; Treatment adherence and outcomes; Antiretroviral therapy (ART); Low and Middle Income Countries

Introduction

Context and Relevance

Despite global advances in the prevention and treatment of HIV, particularly in expanding access to antiretroviral therapy (ART) and decreasing transmission rates, serodiscordant couples, where one partner is HIV-positive and the other is HIV-negative remain a vulnerable and under-researched population, especially in low and middle-income countries (LMICs) [1]. In many regions with high HIV prevalence, especially in sub-Saharan Africa, these couples are not only common but also significantly underrepresented in targeted HIV interventions [2, 3]. The introduction of ART has significantly transformed HIV care, enabling those with HIV to live longer and healthier lives while greatly lowering the risk of transmitting the virus to their HIV-negative partners [4].

This medical advancement has had substantial impact on serodiscordant couples, potentially alleviating some of the stress and anxiety related to transmission risks. Nevertheless, the success of HIV care and treatment in these couples is largely dependent on the dynamics of their relationship. Factors such as communication, trust, and mutual support are vital to adhering to treatment plans and ensuring the well-being of both partners [5]. However, some relationships are often affected by fears of transmission, stigma, mistrust, emotional stress, and rejection, which can lead to non-disclosure and negatively impact treatment adherence and engagement in care [6, 7]. Many people living with HIV (PLHIV) struggle with when and how to disclose their status to their partners, fearing blame, rejection, or violence, which can result in anxiety or depression, and impact treatment outcomes [8].

Current HIV programs often focus on individual-level interventions, often neglecting the relational dynamics that significantly influence health outcomes in serodiscordant partnerships. While quantitative studies have recorded treatment uptake and transmission rates in these couples, there remains a critical gap in qualitative research exploring how relationship dynamics like trust, communication, and support affect treatment trajectories and outcomes [9].

This study seeks to address this gap by examining literature that includes data on lived experiences of serodiscordant couples, concentrating on how relationship factors impact HIV disclosure, treatment adherence, mutual support, and long-term health outcomes. By emphasizing the perspectives of both HIV-positive and HIV-negative partners, this study aims to provide insights that can guide the development of more responsive, couple-centered HIV interventions and policy formulation.

Study Objectives

The primary aim of this study is to investigate how relationship dynamics affect HIV treatment, care engagement, and health outcomes in serodiscordant couples. The specific objectives are to: examine the experiences of HIV-positive individuals in disclosing their status to their seronegative partners, and the emotional and relational outcomes of such disclosures; examine the forms of support provided by HIV-negative partners, and how they affect treatment adherence and overall wellbeing of their HIV-positive partners; explore the impact prior knowledge of HIV has on partners reactions to HIV status disclosure; and provide policy and programmatic recommendations for strengthening couple-based HIV interventions based on evidence from the literature.

Understanding HIV Discordance in Intimate Relationships

HIV discordant couples, also referred to as serodiscordant couples, are intimate partnerships in which one partner is HIV-positive while the other is HIV-negative. These relationships can be found in both marital and cohabitating unions [10]. The term "serodiscordant" emphasizes the disparity in HIV status between partners and the distinct set of health, psychological, and social challenges they encounter in managing the risk of HIV transmission while sustaining a healthy and supportive relationship [11].

Prevalence and Public Health Significance

Serodiscordant relationships are a major public health concern, particularly in regions with high HIV prevalence, such as LMICs. A significant proportion of new HIV infections in these areas occur within stable, long-term discordant partnerships. Research shows that up to 50% of HIV-infected individuals globally are in relationships where their partners are HIV-negative [12, 13]. This highlights the urgent need for targeted interventions tailored to this unique population.

Addressing the needs of serodiscordant couples requires not only medical interventions but also psychosocial support. Couples often face stigma, emotional stress, and concerns about intimacy and reproduction. Understanding the dynamics and lived experiences of serodiscordant couples is essential for designing effective, culturally sensitive public health programs that address both their preventive and emotional needs [14].

Theoretical Framework

This review is guided by a combination of two complementary theoretical perspectives: the Social Ecological Model (SEM) and the Disclosure Process Model (DPM). The SEM explains how individual factors (knowledge, beliefs, emotions, and coping mechanisms); interpersonal factors (partner communications and support); community factors (social norms, stigma, cultural beliefs); and sociocultural factors (healthcare access, policy, legal environments) collectively influence HIV treatment and care [15]. It takes into consideration multi-level factors, ranging from personal emotions and communication to stigma and healthcare access that shape relationship behaviors and health decisions. The DPM explains the process of HIV status disclosure by focusing on three key stages: the decision to disclose (antecedent) which is influenced by stigma, fear, or illness; the act of disclosure (how, when, and to whom), and its outcomes (such as partner support or relationship strain) [16]. Together, these models provide a comprehensive understanding of how internal relationship dynamics and broader social factors affect disclosure practices, treatment adherence, and emotional wellbeing in serodiscordant partnerships. This is demonstrated in Figure 1.

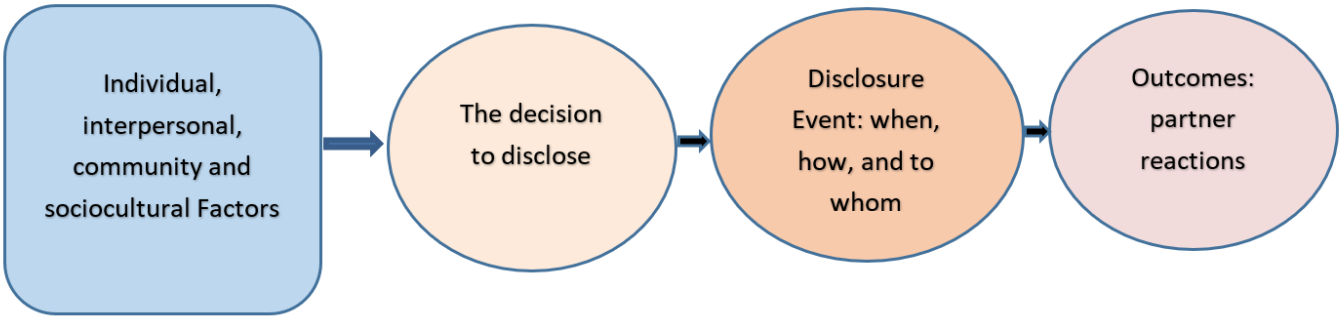
Individual, interpersonal, community and sociocultural Factors
The decision to disclose
Disclosure Event: when, how, and to whom
Outcomes: partner reactions

Figure 1: Integrated Theoretical Frameworks: SEM + DPM (Adapted from [16] by the Authors)

HIV Status Disclosure Between Partners

Disclosing one's HIV status is a crucial moment in any serodiscordant relationship [17]. It is laden with emotional, social, and psychological intricacies. It plays a critical role in shaping the trajectory of the relationship, impacting trust, healthcare access, and long-term treatment involvement [18]. While it is a highly personal decision, it is also a public health priority, and it remains a persistent challenge for PLHIV [19].

The Process and Challenges of Disclosure

Disclosure is often a gradual process rather than a single occurrence. People usually weigh the associated risks and benefits, taking into account factors like the stability of the relationship, their partner's potential reactions, and perceived stigma before revealing their status to their partners [20]. Several key obstacles to HIV status disclosure have been identified. They include: fear of rejection or violence, stigma and shame, and lack of communication skills or supportive environment.

Fear of Rejection or Violence: Some individuals may delay or avoid disclosure due to fears of being abandoned, intimate partner violence, or being blamed, which can result in psychological trauma [21]. A study conducted by Sullivan (2019) revealed that 55% of women and 20% of men living with HIV infection encounter intimate partner violence (IPV), and 24% of women face abuse by their partners after disclosing their HIV status [22]. Another study in Kenya also present evidence of rejection and abandonment of HIV-positive partners by their HIV-negative partners after HIV status disclosure [23].

Stigma and Shame: PLHIV who experience internalized stigma can create feelings of guilt or unworthiness, making it difficult to disclose their HIV status even in committed relationships [24]. This may stem from inadequate communication or counselling during the Pre-and Post-Test Counselling, or from cultural norms or inherent information about HIV. Also, stigma by association, especially from intimate partners, can

hinder HIV status disclosure, and this further impedes open communication and trust among couples [25]. Furthermore, a study conducted by Mashaphu & Pillay (2024) among serodiscordant couples in South Africa revealed that most non-disclosure issues is as a result of stigma fueled by cultural norms [26].

Lack of Communication Skills or Supportive Environment: Many healthcare providers lack the necessary skills to approach the topic sensitively and effectively [27]. In LMICs, those conducting counseling may not be adequately trained to carry out HIV Testing Services (HTS), while others may lack the tools for effective communication [28]. In addition, due to heavy workload or where counselors are pressed to prioritize and meet ART initiation targets, they compromise their ability to discourse issues concerning clients' psychosocial wellbeing [29].

A recent CROI findings highlighted that structured interventions, such as facilitated couple-based counseling, significantly increased rates of safe disclosure, especially in high-prevalence settings in sub-Saharan Africa and Southeast Asia [30].

Effects of Disclosure on Trust, Support, and Treatment Adherence

Trust Building

Disclosure is often perceived as a litmus test for trust in discordant relationships. When it occurs in a safe and affirming environment, it strengthens the emotional bond between these partners and facilitates honest communication [31]. Couples who disclose early and voluntarily are more likely to experience high levels of mutual respect and transparency, contributing to relationship longevity, compared to couples where disclosure is delayed or the information is gotten from a third party [32].

Enhanced Social and Emotional Support

Disclosure enables the HIV-negative partner to assume a more active and supportive role in the healthcare of the HIV-Positive partner, from attending medical visits to offering emotional support [33]. It transforms HIV care into a shared responsibility, reducing the burden on the positive partner. And couples in which disclosure occurred safely showed more significant mutual engagement in ART adherence strategies, such as joint pill-taking and appointment reminders [34].

Improved Treatment Adherence

Numerous studies have documented that non-disclosure is associated with lower adherence to ART. This is primarily attributed to the stress of maintaining secrecy, the inability to take medications openly, and the lack of partner support [35]. Conversely, individuals who disclosed their status to their partners, and received all the necessary support to engage in care recorded improved adherence to treatment compared to those who concealed their status from partners [36, 37]. Furthermore, partner support following disclosure was associated with improved retention in care and reduced rates of depression [38].

Conceptual Framework on HIV Status Disclosure

This framework shows the most common pathway for HIV status disclosure. Partners seek healthcare individually, and when tested and confirmed HIV-positive, they then disclose their status to their partners. This result in reactions such as acceptance or rejection. And these reactions can lead to either improved health outcomes or adverse health and well-being, as illustrated in Figure 2

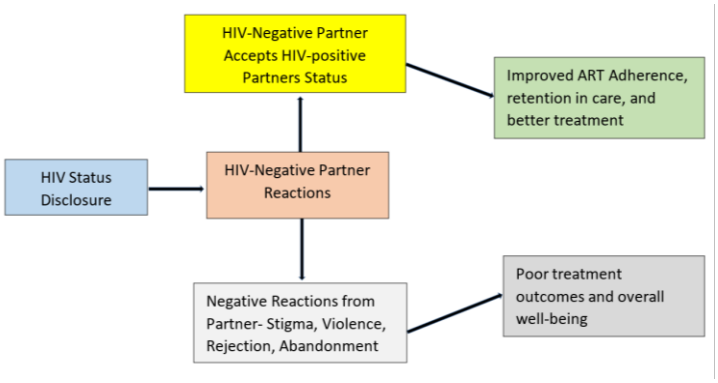
HIV-Negative Partner Accepts HIV-positive Partners Status
Improved ART Adherence, retention in care, and better treatment
HIV Status Disclosure
HIV-Negative Partner Reactions
Negative Reactions from Partner- Stigma, Violence, Rejection, Abandonment
Poor treatment outcomes and overall well-being

Figure 2: Conceptual Framework on HIV Status Disclosure (Adapted from [38] by the Authors)

The impact of Knowledge on Acceptance Rate among Serodiscordant Couples

Studies show that HIV-negative partners who possess high levels of HIV-related knowledge are more likely to accept their partner's HIV-positive status and engage in supportive behaviors than those who do not [39, 40]. Studies across diverse contexts, consistently demonstrate that informed partners are better equipped to understand the implications of viral suppression, ART adherence, and the principles of U=U

(Undetectable = Untransmittable), thereby reducing fear and stigma associated with disclosure [41, 42].

In addition, informed HIV-negative partners are more likely to respond with emotional support, maintain the relationship, and participate in joint prevention planning (e.g., condom use, PrEP uptake, etc) [43]. This acceptance is positively associated with improved treatment adherence, psychological well-being of the HIV-positive partner, and overall relationship stability. Disclosure was higher among partners with better health understanding and who tested together, with high acceptance rate. Conversely, lack of knowledge has been linked to rejection, partner violence, and poor disclosure outcomes [44].

These findings underscore the critical need for couple-based education and counseling interventions that enhance HIV literacy, particularly in high-prevalence settings.

Methodology

Study Design

This study utilized a qualitative research design, guided by a systematic review of literature. The purpose was to synthesize existing qualitative evidence on the influence of support mechanisms after HIV status disclosure in serodiscordant relationships, and relationship dynamics afterwards. The focus was to identify, critically appraise, and thematically analyze peer-reviewed studies that explored complex psychosocial phenomena, such as disclosure dynamics, emotional responses, interpersonal support, and their impacts on treatment adherence and well-being.

Search Strategy

A thorough literature search was carried out using electronic databases such as PubMed, PsycINFO, CINAHL, Scopus, Google Scholar, and websites of WHO and UNAIDS. The search covered studies published between January 2010 and July 2025, using a combination of Medical Subject Headings (MeSH) and free-text terms. Boolean operators (AND, OR) were used to combine terms for a more precise and sensitive search.

("HIV disclosure"[Title/Abstract] OR "serostatus disclosure"[Title/Abstract])

AND ("serodiscordant couples"[Title/Abstract] OR "discordant couples"[Title/Abstract])

AND ("partner reaction"[Title/Abstract] OR "support"[Title/Abstract] OR "relationship outcome"[Title/Abstract])

AND (*"emotional well-being"*[Title/Abstract] OR *"health outcomes"*[Title/Abstract])

AND (*"antiretroviral therapy (ART)"[Title/Abstract]* OR *"HIV treatment adherence"* [Title/Abstract])

AND ("2010/01/01"[Date - Publication]: "2025/07/15"[Date - Publication])

Inclusion and Exclusion Criteria

Inclusion Criteria: Peer-reviewed quantitative, qualitative or mixed-methods research; studies which focused on adults (≥18 years) living with HIV in serodiscordant relationships; reported on partner reactions (e.g., support, rejection, violence, relationship changes); articles published only in English; and articles published from January 2010 to July 2025.

Exclusion Criteria: Articles not focused on PLHIV; editorials, commentaries, and opinion pieces; studies without full-text access; duplicates across database; and articles not published in English.

Article Screening and Selection Process

The literature selection followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. A systematic literature search was conducted across six major databases: PubMed, Scopus, PsycINFO, Web of Science, CINAHL, and Google Scholar, to identify studies examining HIV status disclosure among serodiscordant couples, with emphasis on disclosure processes, partner reactions, and relational or health outcomes. The search covered publications between January 2010 and July 2025 and was limited to studies published in English.

The initial search yielded 1,243 records. After importing the results into Zotero for de-duplication, 963 unique articles remained. These were subjected to a title and abstract screening, during which 777 articles were excluded for not meeting the inclusion criteria. A total of 186 articles were selected for full-text review, after which 92 articles were excluded. Finally, 94 articles met all criteria and were included in this review. This is represented by the PRISMA Flowchart in Figure 3.

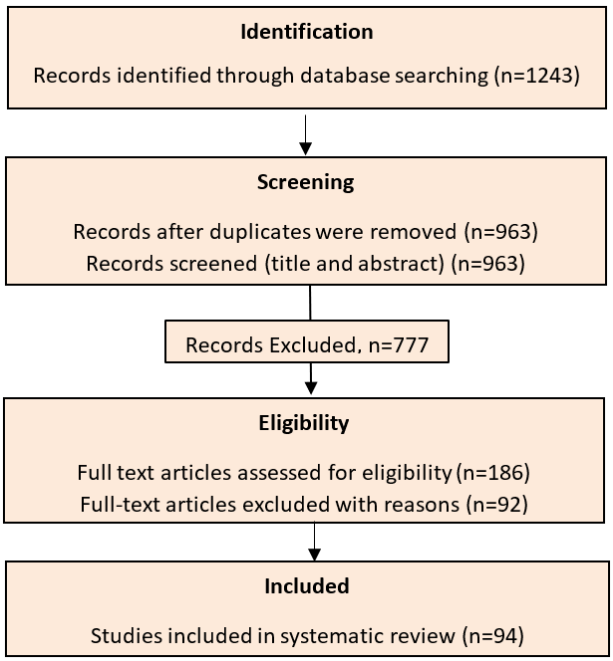
Identification
Records identified through database searching (n=1243)
Screening
Records after duplicates were removed (n=963)
Records screened (title and abstract) (n=963)
Records Excluded, n=777
Eligibility
Full text articles assessed for eligibility (n=186)
Full-text articles excluded with reasons (n=92)
Included
Studies included in systematic review (n=94)

Figure 3: PRISMA Flowchart Showing Article Screening and Selection Process

Data Extraction

A standardized data extraction form was developed to collect the following:

- Study characteristics: author(s), year, country, setting, study design.
- Participant demographics: age, gender, relationship type.
- Disclosure process: timing, motivation, method.
- Support mechanisms: type (emotional, financial, treatment support)
- Key findings related to treatment adherence and well-being.

Quality Appraisal

The Critical Appraisal Skills Programme (CASP) Qualitative Checklist was used to assess methodological quality, including clarity of aims, appropriateness of methodology, ethical considerations, and depth of data analysis. Only studies with acceptable or high-quality scores were retained for analysis.

Data Analysis

A thematic synthesis approach was used to analyze the data. A line-by-line coding of findings from included studies was done. Descriptive themes were developed to organize recurring concepts (e.g., "fear of rejection," "partner encouragement"), and analytical themes generated to interpret how support mechanisms influence adherence and well-being post-disclosure.

Ethical Considerations

As this study is based on publicly available literature, no ethical approval was required. However, ethical standards of transparency and accuracy in reporting were strictly followed.

Gaps Identified

The review was limited to studies published in English, which may have excluded relevant research from non-English-speaking regions. Grey literature was only partially included through Google Scholar. Quality of included studies varied; some lacked detailed methodological reporting. In addition, the findings are dependent on the quality and context of the primary studies and may not be generalizable to all discordant couples.

Findings and Discussion

A total of 94 studies were included in this review, conducted across diverse settings including sub-Saharan Africa, Southeast Asia, and North America. The studies employed in-depth interviews, focus group discussions, and ethnographic observations. Participant groups included HIV-positive individuals in serodiscordant partnerships and their HIV-negative partners.

Navigating the Disclosure Process

Numerous participants delayed or avoided disclosure because of concerns about negative partner reactions, discrimination, or abandonment [21]. Disclosure were often influenced by relationship dynamics, pregnancy, or health crises. For example, in a study conducted in Uganda, an HIV-positive client stated, "I was afraid he would leave me. But after I got sick, I had to tell him" [45]. Also, some disclosures occurred spontaneously, whereas others were facilitated by healthcare providers [46, 47].

Lived Experiences after Disclosure

The study's findings offer valuable insights into the experiences of HIV-positive partners in serodiscordant relationships, especially after disclosing their HIV status. Emotional support was identified as a key theme that emerged, characterized by affirming and empathetic responses from HIV-negative partners. Statements such as "She makes me feel I'm not alone" highlight the protective role of emotional reassurance in mitigating psychological distress among serodiscordant couples [48]. This aligns with existing literature that emphasizes that emotional support is a crucial factor in mental well-being and treatment adherence among

PLHIV [49]. Experiences surrounding HIV status disclosure varied. Many individuals reported positive reactions from their partners. One pregnant HIV-positive participant in a study in South Africa shared "It was fine. He also got tested after I told him, and he was negative…he was very supportive, reminded me when to take my medicine." [50]. These findings underscore the importance of partner acceptance in alleviating the fear of stigma and rejection, which are common barriers to early disclosure [51].

When met with acceptance, disclosure can build trust and improve treatment continuity in discordant relationships, leading to successful treatment outcomes and viral suppression, thereby increasing the chances of having children without HIV infection [52]. In addition, coping strategies and communication emerged as key resilience factors. More recent studies show that open dialogue between partners fosters mutual understanding and collaborative decision-making regarding treatment and sexual health [53, 54]. Open communication has been linked to higher relationship satisfaction and lower HIV transmission risk, highlighting its central role in the successful management of HIV status discordance [55].

Despite these positive narratives, challenges such as stigma and discrimination still persist. "Many of my friends refuse to come near me when they heard" shared an HIV-positive male partner [56]. This underscores the external social pressures that discordant couples face. This finding is consistent with documentation from literature, and highlights the pervasive role of community stigma in isolating HIV-affected individuals and impeding their social integration. Such experiences can indirectly affect treatment adherence and psychological health by eroding social support systems. Some participants described unsupportive and even harmful responses from their partners, including statements like "If I tell him, he may refuse to take care of my child…. As soon as he gets to know I am HIV+, he will run away and leave me." [50]. These narrative reveal the potential for severe interpersonal and emotional consequences after disclosure. Rejection and abandonment can contribute to internalized stigma, depression, and disengagement from treatment. The heterogeneity of partner responses emphasizes the need for interventions that support both members of discordant relationships, particularly during the disclosure process and post-disclosure counseling.

Role of Support Mechanisms Post-Disclosure

Disclosure can facilitate the development of emotional intimacy, encouragement, and a sense of shared responsibility. Partners play a crucial role in reminding PLHIV to adhere to medication regimens, attend clinic appointments, and manage daily challenges [57]. Following HIV status disclosure, many participants in South African serodiscordant relationships described how their partners consistently reminded them or supervised their medication intake, providing practical support that became a key source of emotional strength [58]. *Additionally, c*ounseling, couple-based interventions, and peer support groups were instrumental in stabilizing relationships following disclosure [59, 60]. Table 1 is a summary of emerging themes from the content analysis.

Table 1: Summary of Emerging Themes from Thematic Content Analysis Post-Disclosure

Theme Code	Theme Description	Sample Quote
T1	Emotional Support from Partner	"He always reassures me I'm not alone."
T2	HIV Status Disclosure Experiences	"It was hard, but he accepted me."
T3	Coping Strategies and Communication	"We talk openly about everything."
T4	Stigma and Discrimination Challenges	"Some friends stopped visiting us."
T5	Practical Support (e.g., attending appointments)	"He/She comes with me to the clinic."
T6	Unsupportive behavior	"Relationship ended"

Impact on Treatment Adherence and Well-being

Emotional and practical support significantly contributed to consistent ART use [61]. Also, disclosure, combined with partner support, enhanced self-esteem, reduced anxiety, and improved mental well-being. In the absence of blame from the HIV-negative partner, HIV-positive individuals were motivated to pursue

healthier lifestyles. However, in certain contexts, gender power imbalances and community-level stigma remained obstacles to sustained adherence [62]. Moreover, studies from various contexts provide insights into experiences post disclosure. A study conducted in four African countries, Kenya, Uganda, Burkina Faso and Malawi, among 157 PLHIV who disclosed their status to their partners revealed that most HIV-positive partners received substantial emotional and practical support post-disclosure, although some encountered stigma and strained relationships [63]. Increased knowledge about HIV reduced fear among partners [64]. In Hanoi, Vietnam, participants expressed significant concerns about stigma and breaches of confidentiality; and selective disclosure sometimes hindered access to care. Participants weighed the relevance of disclosure against potential risks [65, 66].

Partner Support in Serodiscordant Relationships

Partner support was another crucial area explored following disclosure. The types of support and their impact on treatment adherence and outcomes are examined here.

Emotional Support and mental health

Emotional support is crucial in HIV care for positive partners. Those who received encouragement, emotional comfort, and companionship from their HIV-negative partners experienced reduced self-stigma and improved adherence to their treatment plans [67]. This support was evident through active listening, expressions of care, and shared optimism about managing HIV. High levels of emotional support are linked to better mental health outcomes and consistent adherence to ART [68]. Participants who felt emotionally supported reported lower levels of depression and anxiety, which facilitated better engagement with the treatment regimen [69]. Reassurance and emotional stability from partners strengthened the relationship bond and enabled the HIV-positive partner to feel valued and safe. This security reduces fears of abandonment and fosters mutual commitment [70, 71]. However, despite these benefits, some participants encountered challenges, such as internalized self-stigma, fear of burdening their partners with their health issues, and emotional distancing from HIV-negative partners who struggled to cope with the diagnosis. These factors sometimes lead to reduced communication and support within the relationship [72].

Financial and Practical Support

Financial and practical support included assistance with transportation to clinics, purchasing medications (when necessary, especially for the management of opportunistic infections), and ensuring food security. Financial support from partners enabled consistent attendance at clinic appointments, purchasing nutritional supplements, and access to better-quality healthcare [73, 74]. In many contexts, the cost and effort required to access healthcare facilities was a major barrier. Studies revealed that transportation assistance improved access to healthcare services, which is crucial for ensuring timely ART adherence and ongoing monitoring [75]. Ensuring food security is vital, as food insecurity is associated with decreased ART adherence and poorer health outcomes [76, 77]. Lower financial stress improves mental health and allows HIV-positive partners to focus on treatment and recovery [78, 79].

Health Management Support

Health management support involved the direct and indirect actions HIV-negative partners took to support their HIV-positive partners in staying engaged with healthcare services, adhering to ART, and maintaining general well-being. In serodiscordant couples, the involvement of the HIV-negative partner in health routines significantly strengthened treatment outcomes and reduced the burden of the disease [80]. Active participation by the HIV-negative partner in health management is associated with improved treatment adherence and better health outcomes. HIV-negative partners often supported their partners by keeping track of follow-ups and reminding their partners about upcoming visits [81]. In addition, physically accompanying a partner to the clinic resulted in reduced anxiety, provided emotional reassurance, and signaled a shared commitment to health. Studies have revealed that when partners accompany each other to medical appointments, it strengthens their relationship and enhances adherence to HIV care [82].

The multifaceted nature of partner support in serodiscordant relationships: emotional, financial, and health management support from HIV-negative partners significantly contribute to the well-being and treatment adherence of HIV-positive individuals [83]. However, challenges such as fear, gender norm, stigma, financial strain, and limited health literacy can impede the effectiveness of these support [84]. Addressing these challenges through targeted interventions and support services is essential for optimizing health outcomes in serodiscordant couples. Table 2 is summary of the types

of support HIV-positive partners can receive from their HIV-negative partners, the outcomes and associated barriers to such support.

Table 2. Showing Types of Partner Support, outcomes and barriers

Type of Support	Action	Outcomes	Barriers
Emotional Support	Active listening, expressions of care, encouragement, emotional reassurance, companionship	Improved mental health and consistent adherence to antiretroviral therapy (ART)	Stigma, fear, rejection, abandonment, social isolation, anxiety, depression, communication gap
Financial Support	Assistance with transportation to clinics, purchasing medications, and ensuring food security.	Access to healthcare services, treatment continuity, reduced stress levels and improved capacity to attend medical appointments.	Economic disparities, gender dynamics, job insecurity
Health Management Support	Scheduling appointments, Accompaniment to Clinics, reminders to take pills, Advocacy and Communication	Improved treatment adherence and better health outcomes.	Limited HIV knowledge, fear of transmission, health system constraints, time and logistics conflicts

Limitations of the Study

This study did not find much evidence on how couples prior education and knowledge on HIV contribute to reactions of HIV-negative partners following HIV status disclosure. The negative reactions from HIV-negative partners likely stem from the fact that they lack robust knowledge of HIV [85]. Therefore, further research on this is required.

Conclusion

This research highlights the critical importance of disclosing one's HIV status and having supportive networks in serodiscordant relationships, as these factors greatly influence adherence to treatment, health outcomes, and psychosocial well-being. The review's findings indicate that disclosure, when accompanied by a partner's support, be it emotional, financial, or healthcare-facilitated, is essential in managing the intricate dynamics of serodiscordant relationships. Effective partner support often mitigated the negative effects of disclosure, promoting open communication, collaborative treatment planning, and improved health outcomes. On the other hand, stigma, gender power imbalances, and cultural barriers frequently obstructed safe disclosure, negatively affecting treatment results and personal autonomy. These dynamics highlight the dual nature of disclosure as both a driver for better care and a potential vulnerability for rejection. Addressing these issues necessitates culturally sensitive, gender-aware strategies that prioritize the autonomy and safety of PLHIV.

The evidence from literature underscores the need for targeted interventions that consider the social context of HIV, especially within intimate relationships, to enhance the health and well-being of PLHIV in discordant unions in the future. Additionally, transitioning to couple-centered and community-informed models of care is necessary to boost adherence and reduce the psychosocial challenges linked to HIV management. Tailored interventions that target joint-couples education is required before counseling, testing, and status disclosure is done. This would necessitate joint health seeking behavior to medical care and visits to health facilities. Further research is needed to identify

the best methods for integrating couple-focused interventions into existing HIV care services to ensure comprehensive and seamless support.

Recommendations and Future Directions

Based on the study findings, several key actions are recommended for professionals, organizations, researchers, and policymakers.

Couple-based education should be integrated into HIV care, providing education on HIV and its interventions prior to testing and disclosure. This approach can promote mutual understanding, encourage open communication, and ultimately lead to better health outcomes for both partners in the relationship [86, 87, 88]. Trained healthcare workers should empathetically guide this process to ensure informed and safe disclosure. There should be provision of post-disclosure support for couples by establishing follow-up counseling services and offering resources to enable them navigate the process without straining the relationship [89, 90]. Gender-sensitive approaches that empower both men and women to disclose safely should be promoted. This includes the use of risk assessment tools, legal protections where appropriate, and the active engagement of male partners in HIV prevention and care, especially in patriarchal societies where power imbalances may hinder open communication [91, 92]. Furthermore, anti-stigma initiatives should be integrated into stigma-awareness training within healthcare and community-based systems to foster greater acceptance and support for serodiscordant couples [93, 94]. Further research should be conducted to explore the long-term effects of disclosure on antiretroviral therapy adherence, relationship dynamics, and overall well-being.

Acknowledgments

Author Contributions: Conceptualization, E. F.; methodology, E. F. and T. D.; literature search and data curation, E. F.; O. N. E.; O. O. M. and O. N.; original draft preparation, E. F.; O. O.; T. D. and O. A.; writing and editing, O. N.; O. N. E. and E. T. D. All authors have read and agreed to the published version of the manuscript.

Disclosures: The authors declare that no generative AI was used in the writing of this manuscript. The authors take full responsibility for the content of the manuscript.

Funding: No funding was received for this review.

Conflict of interests: The authors declare that there is no conflict of interests.

Ethical Approval: Not Applicable.

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Epidemiology & Health Data Insights
(eISSN 3080-8111)

Review Article

Addressing the Digital Divide: Strategies for Inclusive Telehealth and AI in Resource-Limited Settings

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Received: Aug 21, 2025
Accepted: Sep 13, 2025

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Abstract:

The COVID-19 pandemic accelerated the adoption of telemedicine and artificial intelligence (AI), transforming healthcare delivery worldwide. These technologies hold promise for improving access, efficiency, and diagnostic accuracy, but their benefits remain unevenly distributed. In many low- and middle-income countries (LMICs), persistent gaps in infrastructure, affordability, literacy, and governance risk turning digital innovation into a driver of health inequities. This paper examines the *digital divide* as a multidimensional health determinant encompassing infrastructure, affordability, human capacity, sociocultural inclusion, and governance. Using illustrative case studies from Africa, South Asia, Latin America, and high-income countries, this study highlights how telehealth and AI can enhance accessibility and enable task-shifting, while also demonstrating how exclusionary design and weak systems may perpetuate disparities. Building on these insights, the paper proposes a multi-sector framework for inclusive digital health, integrating investments in infrastructure, affordable and scalable models, digital literacy, culturally sensitive design, governance reform, sustainable financing, and public–private partnerships. To operationalize this framework, we recommend measurable indicators (e.g., affordability thresholds, literacy benchmarks, governance readiness indices) and propose implementation tools, including a logic model and barrier-to-action checklist. We argue that digital equity must be treated not as a peripheral issue but as a moral imperative for global health justice. Achieving this requires embedding equity into design, financing, and governance from the outset so that telehealth and AI reduce, rather than exacerbate, disparities in healthcare.

Keywords: Telehealth; Artificial Intelligence; Healthcare, Digital Divide; Health Equity; Global Health Policy; Resource-Limited Settings

Introduction

Telehealth and artificial intelligence (AI) are increasingly recognized as transformative technologies in global healthcare delivery. For this paper, the *digital divide* is defined as the inequitable distribution of access to digital infrastructure, affordability of devices and services, digital literacy, and enabling governance structures that determine who can benefit from digital health innovations. The scope of this analysis covers Africa, South Asia, Latin America, and high-income countries (HICs), with a focus on health systems, governance, and cultural factors shaping telehealth and AI adoption in the post-COVID-19 era (2020–2025) [1,2].

This manuscript is structured as a narrative review with policy analysis, synthesizing illustrative evidence from multiple regions to identify equity barriers and propose a comprehensive framework for inclusive digital health. These technologies could make it easier for individuals to seek treatment by enabling remote consultations, digital diagnostics, and algorithm-supported decision-making. They also hold potential to reduce costs and standardize care in resource-limited health systems. The COVID-19 pandemic accelerated their global adoption, demonstrating their value during emergencies while also highlighting persistent inequities in access.

The digital gap includes differences in infrastructure, internet access, device ownership, cost, and digital literacy. It also covers less obvious factors, like cultural obstacles, gender inequalities, language exclusion, and broken governance structures that affect how fairly digital health solutions are used. These gaps could make it harder for telehealth and AI to achieve their goals of improving health equity in many low- and middle-income nations, where the need for new health solutions is highest [3].

Much research shows that telehealth and AI are being used more and more quickly, especially because of the pandemic. However, not many studies look at how to make sure that all people can use these technologies in different, resource-limited settings. The literature frequently stresses technological feasibility or efficiency improvements, while insufficiently addressing the social, cultural, and policy factors that influence fair adoption. This study fills that vacuum by bringing together learning from many areas and industries and suggesting a multi-level strategy framework that includes investments in infrastructure, training people, and changing the way government works.

The analysis is framed by two leading questions: (1) What is the impact of the digital gap on the equitable adoption of telehealth and AI? and (2) What solutions tailored to the circumstances can effectively and sustainably close these gaps? By answering these questions, the report gives us a path for the future of inclusive digital health.

Methods

This paper adopts a narrative review with a policy analysis approach. The objective was to synthesize evidence on how the digital divide shapes the equitable adoption of telehealth and AI across diverse contexts and to propose a multi-sector framework for inclusion.

Search strategy and sources. Evidence was gathered from peer-reviewed articles, systematic and scoping reviews, and policy reports published between 2018 and 2025. Databases consulted included PubMed, Scopus, and Web of Science, complemented by grey literature from organizations such as the World Health Organization (WHO), International Telecommunication Union (ITU), and World Bank. Search terms combined keywords such as *telehealth, artificial intelligence, digital divide, health equity, low- and middle-income countries, governance,* and *policy*.

Inclusion and exclusion criteria. We included studies and reports that (i) examined the adoption of telehealth or AI in healthcare, (ii) explicitly addressed issues of access, equity, or governance, and (iii) provided region-specific insights (Africa, South Asia, Latin America, or high-income countries). Excluded were studies focusing solely on technical performance (e.g., algorithm accuracy) without an equity dimension.

Case selection. Illustrative case studies were drawn purposively from regions where digital health programs had documented successes, persistent barriers, or innovative policy responses. Selection was guided by the diversity of health system contexts rather than representativeness alone.

Synthesis. Themes were derived inductively by comparing evidence across regions. Barriers, enablers, and gaps were analyzed within five domains—infrastructure, affordability, human capacity and literacy, sociocultural context, and governance—which informed the development of the proposed multi-sector framework.

The Digital Divide in Healthcare

People commonly talk about the digital divide in terms of technology infrastructure, such as whether or not areas have broadband internet, stable electricity, and access to digital gadgets. These aspects are essential, but viewing the divide just as infrastructure neglects the intricate social, economic, and political dynamics that ultimately influence access and use. This limited perspective may portray telehealth and AI adoption as merely a question of "building networks," when equality is contingent upon a significantly broader array of elements. This study broadens the notion of the digital divide in healthcare to encompass not just infrastructure but also affordability, human capability, societal barriers, and governance deficiencies that delineate who benefits and who remains marginalized [3,4].

Infrastructure is still the most obvious problem. In a lot of low- and middle-income countries (LMICs), rural and peri-urban areas still don't have dependable internet or energy. This makes it hard for both patients to get telehealth services and for clinicians to provide them. Even when there is coverage, limited bandwidth might make complex AI-based apps unusable.

Affordability is a second way to keep people out. Many families can't use digital health platforms because smartphones, PCs, and data plans are too expensive. For providers, the price of subscribing to AI-enabled software or teleconsultation platforms can be too high, especially in health systems that don't have enough money. So, without government help or low-cost options, telemedicine and AI could only be useful for rich people [5].

Digital literacy and human capacity are both very crucial. Patients need to know how to use teleconsultation tools, interpret digital health information, and trust AI-based recommendations. Health workers need to learn how to use digital tools and how to think critically about what they make so that they don't rely on them too much. If we don't put money into digital literacy, the gap moves from access to useful use [1].

People's utilisation of digital health is also affected by sociocultural barriers. Language barriers, unequal access to technology for men and women, and cultural suspicion of machine-driven care can all make it hard for those who are already on the fringes to seek treatment. For example, women in some places don't have much influence over who can have a mobile phone, and minority groups might use platforms that don't take their language or culture into account.

Lastly, bad rules and poor governance make things worse. People aren't adopting because it's hard to know how to get paid back, the rules aren't always the same, and the rules for protecting data aren't strong enough. Additionally, without purposeful equity-focused policies, digital health programs can sometimes make existing inequities worse instead of fixing them [6].

When you look at all of these factors together, they show that the digital divide in healthcare needs to be thought of as more than just a technological issue. The current discourse is lacking because it only talks about infrastructure, which hides the social, economic, and cultural factors that really make a place inclusive. This study contends that to bridge the divide, it is essential to adopt a comprehensive perspective that encompasses not only the development of networks but also the consideration of affordability, human capability, sociocultural inclusion, and governance reform as interconnected foundations for equitable telehealth and AI implementation. We created a conceptual framework (fig. 1) to show that the digital gap is more than just infrastructure. It shows that there are many different types of hurdles to adopting digital health [7].

Multidimensional Digital Divide in Healthcare

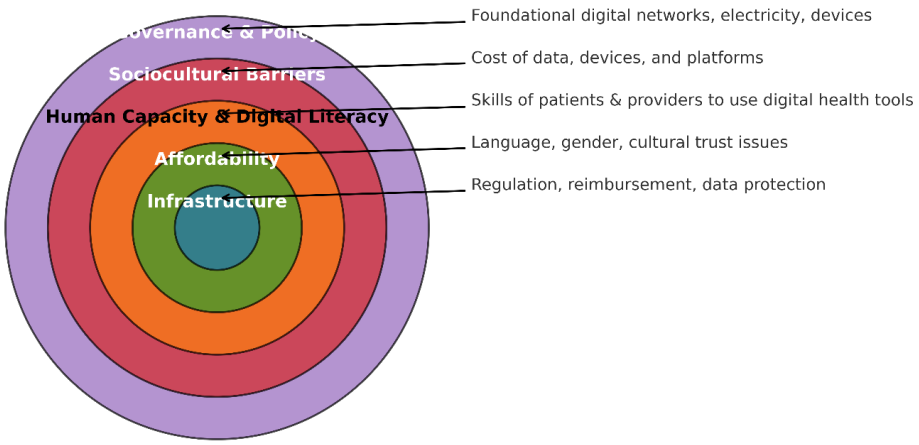
Foundational digital networks, electricity, devices
Cost of data, devices, and platforms
Skills of patients & providers to use digital health tools
Language, gender, cultural trust issues
Regulation, reimbursement, data protection
Sociocultural Barriers
Human Capacity & Digital Literacy
Affordability
Infrastructure

Figure 1. Multidimensional Layers of the Digital Divide in Healthcare. This figure depicts the digital divide as a layered construct encompassing five interrelated domains. At the core lies infrastructure (internet connectivity, electricity, devices), which provides the foundation for digital health access. Surrounding this are issues of affordability (costs of devices, data plans, and platforms) and human capacity and digital literacy (skills of patients and providers to effectively use telehealth and AI tools). The outer layers highlight sociocultural barriers, including language, gender inequities, and cultural trust, as well as governance and policy, which encompass regulation, reimbursement mechanisms, and data protection frameworks. Together, these dimensions underscore that bridging the digital divide requires comprehensive strategies that address structural, social, and regulatory determinants of inclusion.

Impact of Telehealth and AI in Resource-Limited Settings

The use of telemedicine and AI in places with few resources has made people both hopeful and cautious. A lot of the current conversation is about technical performance, such as speed, accuracy, and the ability to grow. Although these measurements are significant, they fail to encompass the entire range of repercussions. This article transcends the dichotomy of "benefits versus risks" by examining how telehealth and AI transform behavioural dynamics, professional practice, and structural equity within vulnerable health systems[8].

These technologies offer substantial opportunities. Telehealth platforms make it easier for people in rural areas to get care by connecting them with specialists in cities. This breaks down geographic boundaries that have made it hard to get care in the past. AI-powered diagnostic solutions can cut costs by making laboratory work easier, giving frontline workers automated decision aids, and making specialised information more accessible. This makes things more affordable in health systems that are already stretched thin and don't have enough staff. Task-shifting is also significant. This is when digital tools let nurses and community health professionals do tasks that doctors usually do. AI-based malaria tests in rural sub-Saharan Africa are a very good example. Portable gadgets that use image-recognition algorithms can look at blood smears in a matter of minutes. This means that doctors don't have to rely as much on busy lab specialists, and treatment decisions may be made faster. These new ideas show how AI can help doctors diagnose patients in locations where there aren't enough doctors. But they also show that structural problems, like unreliable electricity, expensive maintenance costs, and the need for continual training, could make sustainability harder to achieve [1,8].

There are also a lot of risks that come with this change. Telehealth and AI could make things worse for people who don't have access to the internet, are illiterate, or don't have enough money. As people become more reliant on outside technology, local capacity can suffer. This makes health systems less stable when systems fail, equipment breaks, or commercial vendors pull out. Also, women, the elderly, and those who speak different languages are more likely to be left out when platforms are made without taking culture, gender, or multilingual interfaces into account. These dynamics affect trust, professional autonomy, and long-term resilience in addition to access. They also affect how healthcare staff and patients use digital systems.

The significant deficiency in contemporary research is the lack of comparison evaluations of equality results among low- and middle-income countries (LMICs). Although case reports record individual successes or failures, there is a scarcity of research that systematically assesses how digital health interventions spread benefits and hazards across various populations. To make sure that telemedicine and AI don't make health inequities worse, it's important to understand how they affect diverse groups of people in different ways. This study redefines digital health as both an innovation challenge and a justice issue in global health by connecting technological advancements to behavioural and systemic equitable results [9,10].

Case Studies / Illustrative Examples

To synthesize insights across regions, we compared the key equity barriers, successful approaches, and persistent gaps identified in Africa, South Asia, Latin America, and high-income countries (Table 1)."

Table 1. Comparative Analysis of Equity Barriers and Responses Across Regions

Region	Key Barriers	Successful Approaches	Remaining Gaps
Africa	Limited internet/electricity, high device/data costs, weak infrastructure	Mobile health (mHealth) via SMS for maternal/child health; AI malaria diagnostics with smartphones	Sustainability issues (power outages, high costs); poorest households excluded[11]
South Asia	Rural–urban disparities, gender inequities in phone ownership, and low digital literacy	Low-bandwidth teleconsultation platforms; AI triage systems; community health worker integration	Persistent gender gap; literacy barriers limit women and older adults[12]
Latin America	Remote geography (Amazon/Andes), fragmented governance, uneven reimbursement	Large-scale public–private telehealth partnerships; AI-assisted diagnostics in underserved communities	Regulatory inconsistency; rural/Indigenous communities remain underserved[13]
High-Income	Affordability gaps, digital literacy in older adults, and language exclusion	Telehealth integration into mainstream health systems; multilingual/migrant-focused digital platforms	Persistent rural gaps; older adults and low-income groups underrepresented[14]

This table summarizes key barriers, successful approaches, and remaining gaps in the adoption of telehealth and AI across Africa, South Asia, Latin America, and high-income countries. Examples and evidence are drawn from recent reviews and regional studies, including Gilano et al. (2024), Cuadros et al. (2025), Qoseem et al. (2024), Eslami Jahromi & Ayatollahi (2022), Aldosari et al. (2023), Camacho-Leon et al. (2022), Daniela Chueke (2023), Shi et al. (2024), and Money et al. (2024).

Looking at case studies from different areas can help us understand both the good and bad sides of digital health. Innovative projects in Africa, South Asia, Latin America, and even high-income countries show that there are still unfair situations. One major flaw in the current literature is that these cases are generally isolated, which makes it hard to learn more general principles. This research combines them to show patterns that can help people around the world adopt telehealth and AI in a fair way.

Africa. Mobile health (mHealth) platforms are now a big part of providing care to areas of sub-Saharan Africa that don't get enough of it. For example, programs that help mothers and children stay healthy send SMS messages to remind them of appointments and teach them about health. There are other tests going on using AI-powered tools, such as malaria diagnostic platforms that let community health workers use smartphone-based microscopy to find infections. These projects show how mobile penetration can be used to get around deficiencies in infrastructure. But they also show problems with sustainability, such as power outages, slow internet speeds, and expenses that are still too high for the poorest households [15].

South Asia. Low-bandwidth teleconsultation systems have helped fill gaps in the number of medical specialists in India, Pakistan, and Bangladesh, especially in rural areas. AI-powered triage systems are also employed to help hospitals that are too full keep track of their patients. Adding community health workers to digital platforms has been a key aspect in their success since it has made them culturally acceptable and built trust with patients. Still, differences between men and women in phone ownership and computer literacy make it harder for women to get care, and women make up a large part of the patients who don't get care. The area shows both how useful task-shifting with technology can be and how it may make current disparities worse [1,16].

Latin America. Brazil and Colombia, for example, have used large-scale telemedicine programs to reach people living in the Amazon and Andes mountains. Public-private collaborations have been very important in making more connections and offering AI-assisted diagnostic services. These programs have made it easier for people to get help, but they also show how hard it is

to govern. Different rules and regulations for paying for care make access uneven. For example, richer metropolitan patients often have better access than rural or Indigenous groups.

For high-income countries, it may be surprising, but digital disparities still exist in places with advanced technology. Older persons, low-income groups, and people living in rural areas in the United States still don't use telehealth as much as they should because of cost and lack of computer literacy. In other parts of Europe, migrant populations also risk exclusion when platforms don't support several languages. These examples show that the digital gap is not just a problem in LMICs; it is a problem for everyone [17].

When you look at all of these situations together, you can see a pattern: digital tools can make things easier and more accessible, but their advantages aren't always shared equally unless fairness is built in from the start. This study advocates for a transition from analysing case studies in isolation to recognising common structural challenges—such as affordability, literacy, governance, and cultural inclusivity—that must be tackled to promote global health equity through telehealth and AI. We plotted differences in internet access, device ownership, and digital literacy by region to show how digital health preparation is not equal across the country (Figure 2) [18].

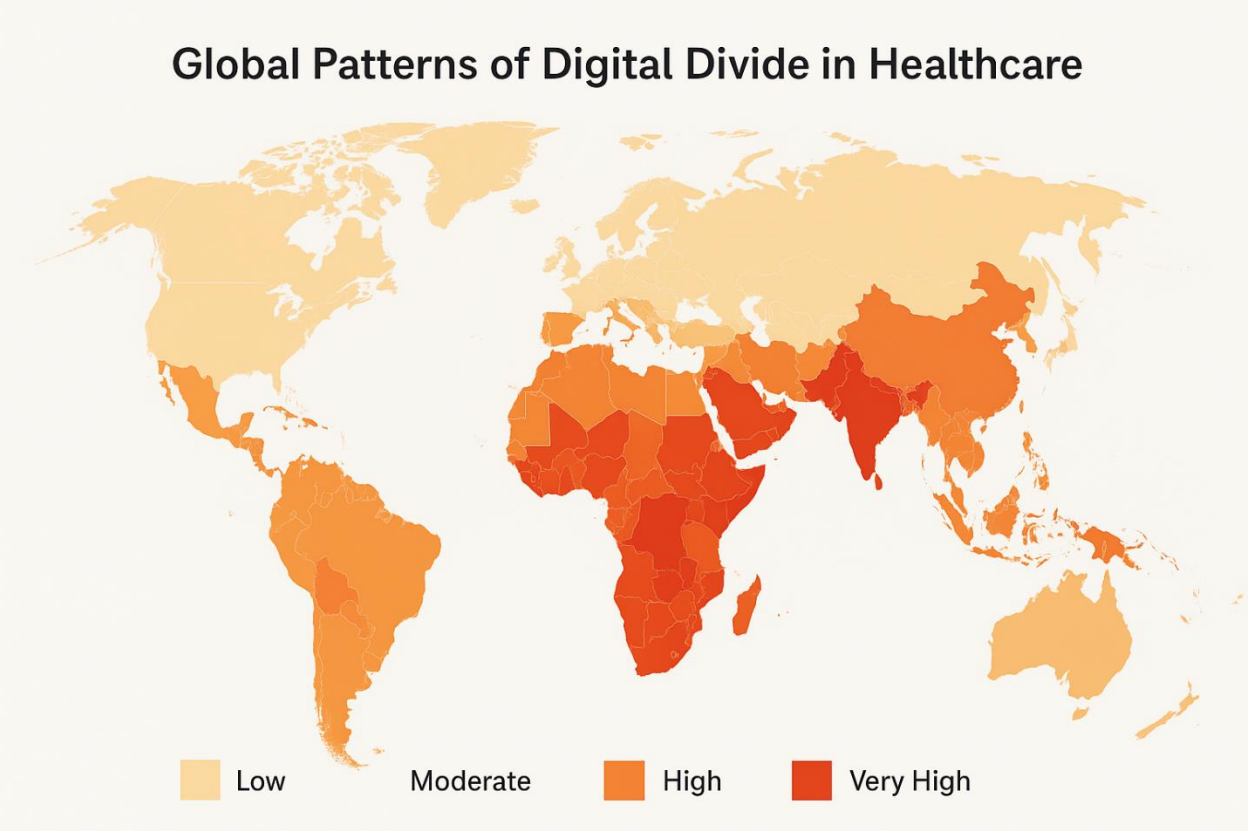

Figure 2. Global Patterns of the Digital Divide in Healthcare. *This thematic world map depicts global patterns of the digital divide in healthcare. Regions are shaded from low (light) to very high (dark) levels of disparity, reflecting differences in internet connectivity, device ownership, and digital literacy. The map highlights that inequities are not confined to low- and middle-income countries but also persist in high-income settings, underscoring the universality of digital exclusion as a health determinant.*

Strategies for Bridging the Digital Divide

Bridging the digital divide in telehealth and AI requires more than piecemeal interventions. Existing approaches often focus narrowly on infrastructure or short-term funding, resulting in fragmented outcomes and unequal access. To move beyond this, we propose a comprehensive, multi-level strategy framework that integrates infrastructure, affordability, literacy, culture, governance, financing, and partnerships into a cohesive roadmap. This framework draws lessons not only from health but also from aviation safety, education technology, and financial inclusion, where systems-level safeguards have been essential for equitable innovation.

Building on these findings, we developed a comprehensive multi-sectoral framework to guide inclusive adoption of telehealth and AI in resource-limited settings Figure 3 [19].

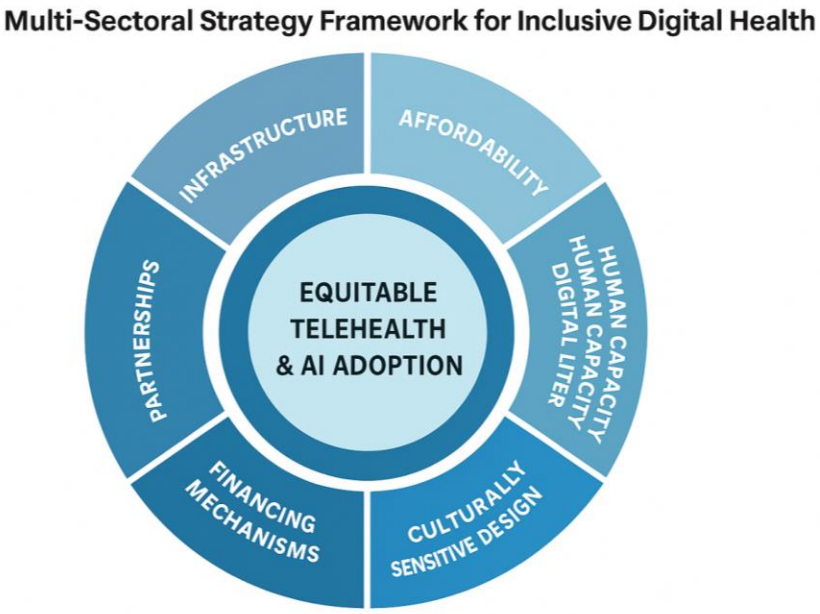

Figure 3. Multi-Sectoral Strategy Framework for Inclusive Digital Health. *This framework illustrates the interconnected strategies required to bridge the digital divide in healthcare. At the core lies equitable telehealth and AI adoption, surrounded by seven interdependent domains: infrastructure, affordability, human capacity and digital literacy, culturally sensitive design, governance and regulation, financing mechanisms, and public–private partnerships. The layered wheel design emphasizes that progress requires integrated, multi-level interventions rather than isolated fixes, reframing digital inclusion as a systemic health determinant.*

Investing in infrastructure. A fair telehealth and AI system needs a strong digital infrastructure. For a lot of low- and middle-income nations (LMICs), this includes bringing internet and mobile service to rural regions, investing in solar-powered or battery-powered alternatives for electricity, and building community digital hubs. Aviation safety lessons show how important redundancy is: just like planes have backup systems to keep them from crashing, digital health systems need to have backup means to connect to avoid service interruptions. Pilot projects in East Africa that used both satellite internet and local Wi-Fi show how blended infrastructure models can keep things running smoothly in tough situations [20].

Models that are affordable and can grow. Even when infrastructure is in place, costs are still a big problem. Telehealth consultations, mobile data contracts, and AI platforms need to be cheap or free for people who are at risk. Financial inclusion programs offer valuable comparisons, as microfinance and tiered payment systems have broadened access to banking services. In health, similar methods, like teleconsultation apps with low data usage or insurance plans that include telehealth services, can make access more equal. SMS-based health advice platforms in Bangladesh highlight how low-cost ways can help people who don't have cellphones or wifi.

The ability of people and their digital literacy. To make sure that meaningful use happens, both patients and providers need to invest in their skills. To keep diagnostic autonomy, it is important to teach health personnel how to think critically about AI outputs instead of just accepting them as they are. Basic digital literacy training can help patients feel less scared and suspicious of new technologies [21]. Education technology offers a paradigm: interactive, localised e-learning modules have effectively enhanced literacy among adults in resource-limited environments. In the same way, simulation-based retraining, which is widespread in aviation, might be used for doctors and nurses. They would need to practise manual diagnosis without AI help regularly to keep their basic skills sharp.

Design that is culturally aware and focused on people. Digital platforms should be made with users in mind, not merely for them. Adoption is made harder by cultural scepticism of decisions made by machines, gender inequality in mobile phone ownership, and language barriers. Community-led design in educational technology demonstrates that customising platforms to

align with local languages, cultural norms, and gender dynamics promotes continued usage. For telehealth, this could include adding visual assistance for those with limited literacy, making sure that the interface works in more than one language, or adding elements that keep women's privacy safe in patriarchal settings [22].

Rules and laws for governing. A common problem is that regulatory systems are broken apart. To keep patients safe and hold providers accountable, there has to be a unified framework for cross-border teleconsultation, reimbursement, and data privacy. Aviation has taught us how important it is for countries to have the same rules, which makes travel safe across borders. Global health organisations may also help define minimum guidelines for how to utilise AI ethically, and then national governments could change them to fit their own needs. Including fairness in regulations, like requiring physicians to take skill-maintenance courses regularly or making sure that platforms are easy to use, would protect against differences caused by technology [23].

Ways to get money. Funding models that work over the long term are important. When experimental projects are funded by donors, they often don't last long. Public funding should be supplemented by novel mechanisms, such as health bonds, insurance coverage for digital services, and cross-subsidization from customers with higher incomes. The financial inclusion industry shows how tiered payment systems can keep services going while reaching more people. Rwanda's community-based health insurance plan, which pays for some digital services, is a good example of how to finance equity on a large scale [24].

Partnerships between the public and private sectors. Collaborative approaches are also very important for growth and long-term success. Governments set the rules and make sure that the public is held accountable, while tech corporations are good at AI and platform design. Working with local NGOs makes sure that people are culturally aware and involved at the grassroots level. Vaccination campaigns are a good example of how cross-sectoral coordination can help reach a lot of people. In Latin America, public-private partnerships have already brought telehealth infrastructure to remote areas, showing how powerful shared responsibility can be [25].

These initiatives show that closing the digital divide needs a system-level, multi-sectoral approach. The new thing about this approach is that it brings together all the many activities into a single plan, connecting investments in infrastructure to social, cultural, and governance issues. This method offers a paradigm for sustainable and fair digital health adoption by incorporating lessons from other fields, such as aviation's attention on redundancy, education's emphasis on user-centred design, and finance's advances in affordability. The key point is that equity can't be added after the fact; it has to be included in the design, funding, and rules for telehealth and AI from the start [3].

Operationalizing and Measuring the Digital Divide

The digital gap is frequently articulated conceptually; nonetheless, its conversion into quantifiable metrics is crucial for assessment and policy implementation. A useful monitoring system should include both process and outcome measurements from several different areas:

- Infrastructure: the number of homes with dependable internet access, the average bandwidth per person, and the percentage of health institutions with steady electricity and working digital platforms.
- Affordability: the percentage of household income spent on mobile data and devices, and the percentage of the population that can get free digital health services [26].
- Digital literacy and capacity: the percentage of adults who know how to utilise teleconsultation platforms and the percentage of healthcare staff who have been trained to use telehealth and AI tools [21].
- Sociocultural inclusion: the difference in mobile phone ownership between men and women; the number of digital platforms that are available in more than one local language; and how happy the community is with the platforms' cultural appropriateness [27].
- Governance and readiness: the WHO Digital Health Readiness Index shows how well a country is prepared for digital health; there are national telehealth reimbursement rules, and there are laws to protect data.

Stratifiers, including gender, age, where you live (rural or urban), financial level, and minority or Indigenous status, should be used to keep an eye on equity. Over time, implementers can use a dashboard approach to keep track of indicators every year to see how things are doing and where there are gaps [28].

Countries should go beyond vague promises of fairness by adding concrete indicators to digital health frameworks. This way, they can hold people accountable through data-driven monitoring.

Framework Validation and Implementation Guidance

The multi-sector framework put forward in this research presents a systematic approach for inclusive digital health; nonetheless, its legitimacy relies on validation and pragmatic direction for execution. Three complementary strategies are proposed:

1. Building a logic model. A logic model can connect behaviours, outputs, and outcomes to make the causal pathways of equity-focused digital health clearer. For instance:

- Things to do: invest in rural connectivity, pay for data costs, and train community health workers [29].

Outputs: more teleconsultation platforms available, more people able to use technology, and better standards for how to run things.

Outcomes: fair use of telehealth, a smaller gender gap in access, and better health outcomes for groups that are often left out.

2. Agreement among experts and testing. Delphi panels, roundtables, or regional expert meetings that look at the face validity of the framework can all be used to validate it. Pilot studies in chosen LMIC contexts could evaluate feasibility, cultural pertinence, and sustainability before expansion[30].
3. A list of things to do for implementation. A simple checklist can help decision-makers figure out what actions, people, and resources are in their way. For instance:

- Barrier: limited connectivity → Action: use blended infrastructure (satellite + Wi-Fi) → Actors: ministries of ICT and telecom businesses; Resources: universal service funds; Time frame: 2 to 3 years.
- Barrier: high data costs; Action: subsidised data bundles for health platforms; Actors: regulators and telecom carriers; Resources: cross-subsidization; Timeline: right away to a short time from now.
- The framework can be both a theoretical contribution and a practical instrument for governments, donors, and practitioners who want to close the digital gap. This is because it combines a logic model with consensus-building and an executable checklist.

Policy Levers and Sequencing for Inclusive Digital Health

Governments need clear policy levers and a clear sense of sequencing for digital health efforts to go from vision to practice. Several useful tools can speed up the adoption of inclusivity:

- Governance and regulation of Set up codes for teleconsultations and digital diagnostics that will let people get their money back [31].
- Set minimal criteria for data protection to protect patient privacy and develop trust.
- Create cross-border licensing agreements (like those in the African Union or EU) to make sure that specialists can reach more people while still being held accountable [32].
- Ways to get money
- Provide fair data-cost subsidies to at-risk groups, paid for either universal service funds or telecom taxes.
- Add teleconsultations and remote monitoring to universal health coverage (UHC) benefit packages to cover more digital health services.
- Test out health impact bonds and mixed finance plans to keep programs going when donor money ends.
- Help with sequencing
- In places with few resources, the top three things to do right away should be to (i) improve infrastructure (connectivity, electricity), (ii) make things more affordable by giving out subsidies, and (iii) teach both providers and patients how to use technology.
- In places with middle- and high-income levels, parallel efforts can help: (i) harmonise regulations across regions, (ii) include telehealth in UHC plans, and (iii) create better governance mechanisms for AI ethics and accountability.

Policymakers can make sure that telehealth and AI become lasting parts of fair health systems instead of broken pilot projects by combining short-term measures for affordability and access with long-term reforms in governance and financing.

Ethical and Equity Considerations

The quick use of telemedicine and AI has overtaken the creation of ethical guidelines that operate in many different parts of the world. In high-income countries (HICs), discussions about the ethics of digital health have mostly focused on data privacy, liability, and following the rules. These issues are highly important, yet they are only a small part of the total picture. In low- and middle-income countries (LMICs), the ethical landscape is shaped by extra problems, like

weak governance systems, not enough legal protections, and a higher risk of marginalisation for vulnerable groups [33].

One of the most crucial things is keeping data private. Many LMICs lack robust data protection laws, resulting in the potential misuse of patients' sensitive health information. When cloud-based platforms are stored outside of a country's boundaries, it is extremely tough to hold people responsible. Along with privacy, algorithmic bias is another issue. AI technologies that are largely trained on data from HIC populations can misclassify diseases or miss unusual disorders among groups that aren't well represented, which would keep inequality in diagnosis and treatment going [34].

It's also important to consider the risk of leaving out groups that are more likely to be hurt, like women, people who reside in rural regions, older people, and individuals who speak a language other than English. Platforms that don't take into account things like cultural norms, literacy levels, or linguistic variety may make structural disparities worse without meaning to. To address these deficiencies, we must transition from universalist frameworks of ethics to context-sensitive approaches that prioritise inclusivity [35].

This paper's novelty is in reconceptualising digital equity not merely as a marginal concern but as a moral imperative for global health justice. Ethical frameworks must clearly integrate equity, ensuring that digital health interventions reduce disparities rather than exacerbate them. To retain trust and make sure that healthcare systems stay strong, it's crucial to make sure that fairness, openness, and inclusion are part of every phase, from making datasets to putting ideas into action.

Future Directions

The next phase of digital health in resource-limited settings must prioritize sustainability, inclusion, and long-term impact. Emerging connectivity solutions, such as satellite internet and community-owned networks, can expand access beyond the limitations of traditional infrastructure. Equally important is the development of AI systems trained on locally representative datasets to reduce algorithmic bias and improve diagnostic relevance for diverse populations [1,36].

Integrating telehealth within universal health coverage (UHC) frameworks is essential to ensure digital services are not treated as temporary add-ons but as integral components of equitable health systems. To date, most evidence comes from short-term pilot projects, leaving critical knowledge gaps on sustainability, workforce skills retention, and system resilience. Future research must therefore prioritize longitudinal studies to monitor equity outcomes over time and assess whether telehealth and AI narrow or widen disparities [10].

Taken together, these priorities call for deliberate investment in connectivity, context-specific AI training, and integration into health financing schemes. By embedding digital health into long-term policy and evaluation structures, countries can ensure that innovation translates into durable and equitable health gains [37].

Conclusion

This research emphasises that the comprehensive integration of telehealth and AI is contingent upon tackling the digital gap as a fundamental health determinant, rather than a secondary issue. It emphasises that fairness must be embedded into digital health from the start by suggesting a multi-level architecture that includes infrastructure, affordability, literacy, culture, governance, financing, and collaborations. This agenda is based on ethical principles, including protecting privacy, minimising bias, and putting vulnerable populations first. To close the digital divide, we need concerted policy action, long-term funding, and global cooperation. This will make sure that digital health improvements make healthcare systems more efficient, fair, and resilient.

Acknowledgments

Disclosures: The author declares no conflicts of interest.

Funding: This research received no external funding.

Ethics approval: Not applicable. This study is based on previously published literature and does not involve human participants or animals.

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Epidemiology & Health Data Insights
(eISSN 3080-8111)

Methodological Paper

Methodological Note on Predicting One-Year Mortality for Chronic Diseases Using Administrative Data

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Received: Aug 27, 2025
Accepted: Sep 22, 2025

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Abstract:
Chronic diseases remain a leading cause of global mortality, underscoring the need for developing reliable models that predict mortality prediction to guide individualized treatments and optimize resource allocation. This methodological note presents a reproducible framework for predicting one-year mortality in chronic disease patients using large-scale administrative healthcare data. The approach employs retrospective cohort design, year-specific subcohorts, and a stratified 5-fold cross-validation using a broad range of machine learning models. Performance is assessed with multiple metrics, including AUC, sensitivity, specificity, and balanced accuracy, to account for class imbalance. Model interpretability is enhanced through SHapley Additive exPlanations (SHAP), enabling identification of key mortality predictors and their directional impact. The proposed framework is general and can be applied to different chronic diseases. It has already been successfully demonstrated in nationwide cohorts of patients with diabetes mellitus and chronic viral hepatitis in Kazakhstan, achieving AUC values of 0.74–0.80, comparable to international benchmarks despite relying on administrative data alone. The method is scalable and adaptable, allowing integration of laboratory and clinical data with feature selection to address high-dimensionality challenges. Its generalizability and clinical relevance, however, should be validated in practice using enriched datasets across additional chronic diseases and diverse populations.

Keywords: One-Year Mortality Prediction; Chronic Diseases; Machine Learning; SHAP Analysis

Introduction

Chronic diseases pose a significant challenge to global public health due to their prolonged duration, slow progression, and high mortality rates. Despite ongoing improvements in medical care and public awareness, mortality rates for such diseases remain high. According to the World Health Organization (WHO), chronic diseases were responsible for 43 million deaths in 2021, which is approximately 75% of global mortality, excluding those attributable to the COVID-19 pandemic [1].

Given the prolonged nature and relatively predictable progression of chronic diseases, one-year mortality prediction is especially valuable. Longer-term predictions, such as predicting 3-, 5-, 8-year mortality, tend to have lower accuracy and sensitivity due to increased uncertainty from disease trajectory change and external factors. In contrast, one-year mortality is an optimal choice, which provides predictive reliability and clinical utility. This shorter timeframe enables health professionals to develop individualized treatment strategies, make effective resource allocation and implement preventive measures in time. In this context, computational methods, especially machine learning (ML) models, have proven to be highly effective in accurately predicting mortality outcomes [2, 3].

The following methodological approach provides a clear and reproducible framework for predicting one-year mortality among patients with chronic diseases using large-scale administrative data. While the proposed framework was successfully implemented and validated on diabetes mellitus and chronic viral hepatitis patients using administrative data alone [4, 5]; the approach itself is not restricted to these conditions and can be generalized to other chronic diseases. Furthermore, it can be integrated with clinical notes, laboratory and imaging data where available. When enriched administrative data is available, the framework should be modified by introducing feature selection to address high-dimensionality challenges. This flexibility ensures that the approach can adapt to different data environments while maintaining methodological consistency. Nonetheless, its broader generalizability and clinical relevance should be validated in practice using enriched datasets across additional chronic diseases and diverse populations.

Study Design and Cohort Definition

The proposed method adopts a retrospective cohort study design using administrative healthcare data [6]. While a complete, definitive list of all chronic diseases does not exist, the WHO identifies four key categories: 1) cardiovascular diseases (e.g., heart disease, stroke, and hypertension); 2) cancer; 3) diabetes; and 4) chronic respiratory diseases (e.g., chronic obstructive pulmonary disease, asthma) [1]. U.S. agencies such as National Institutes of Health (NIH) [7] and Department of Health and Human Services (HHS) [8] apply a broader definition that also includes conditions like HIV, chronic kidney disease, and chronic viral hepatitis.

Patients diagnosed with chronic disease can be identified using the International Classification of Diseases 10th Revision (ICD-10) codes relevant to that specific disease. The dataset must undergo preprocessing to merge different registries, eliminate duplicate records, and form a comprehensive patient cohort. Clinical and laboratory data can be incorporated where available, enhancing predictive accuracy.

To reflect the temporal aspect of chronic diseases, the dataset is divided into distinct year-specific sub-cohorts. For each observation year, patients who died before the start of that year or who were diagnosed within the year are excluded. This approach ensures that only patients with complete clinical data and confirmed survival status at the beginning of the observation period are included.

Figure 1 depicts six types of patient groups in a typical dataset. A triangle represents the date of disease diagnosis, while a circle represents the exit date, which indicates the patient's death. For illustration, we select the third year of observation (red). The subcohort for the third year consists of two patient groups:

- **Case group** – patients diagnosed before the beginning of the third year who died during that year.
- **Control group** – patients diagnosed before the beginning of the third year but who remained alive during that year (similar to cases 2 and 4, which are also highlighted by blue lines and markers).

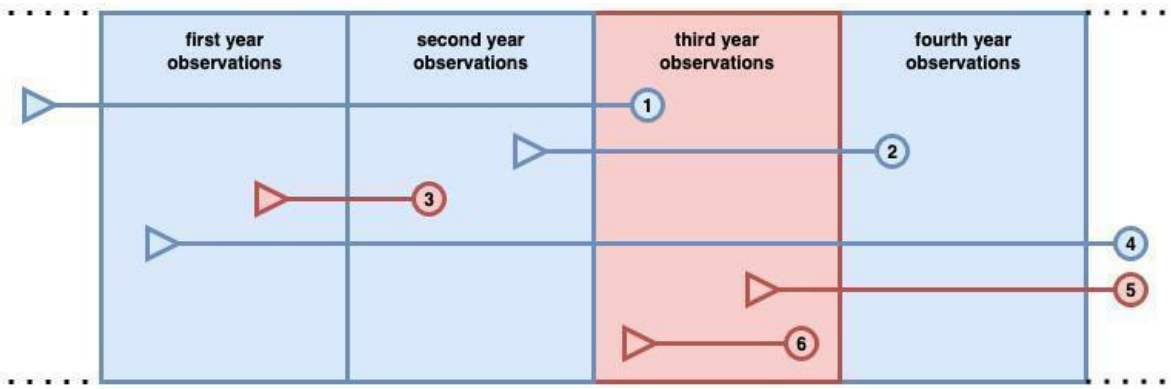

Figure 1. Description of subcohort selection

Patients who died before the start of the third year were excluded from the subcohort (e.g., case 3). Similarly, patients who were newly diagnosed during the third year were also excluded (e.g., cases 5 and 6). Only patients with available clinical information who were alive up to the end of the second year were included. Therefore, we selected subcohorts for the third year and predicted one-year mortality for all patients. It is also important to note that diseases may occur much earlier than the recorded diagnosis date.

Model Development and Validation

Selecting appropriate predictive models is critical for obtaining reliable mortality predictions. In our framework, we evaluate a diverse range of algorithms commonly used in health outcome prediction, including linear models, such as Logistic Regression (LR) [9] and Support Vector Machines with linear kernel (SVM) [10], Gaussian Naive Bayes (GNB) [11], K-Nearest Neighbors (KNN) [11], Discriminant Analysis (LDA, QDA) [12], Ensemble methods such as Random Forest (RF) [13], LightGBM (LGB) [14], XGBoost (XGB) [15], AdaBoost (ADB) [16], and Gradient Boosted Regression Trees (GBRT) [17].

The choice of these models can be rationalized based on their proven efficacy in prior studies predicting chronic disease outcomes, mortality, or similar health-related events [2, 3, 18-20].

Each year-specific cohort is initially divided into a training set (80%) and a held-out test set (20%) using a stratified random split to preserve class distribution. Model selection and tuning are conducted via grid search with stratified 5-fold cross-validation:

1. The training set is split into five equally sized folds using a stratified random split, maintaining a class label ratio across each fold to mitigate imbalance.
2. In each iteration, one fold is set as the validation set, and the remaining four folds are combined as the training set.
3. Standardization is applied based on the training folds to ensure consistent scaling.
4. Models are trained on these folds using the predefined set of hyperparameters and evaluated on the validation fold using the Area Under the ROC Curve (AUC), a threshold-independent metric suited for imbalanced data.
5. This procedure repeats for every hyperparameter combination across all 5 folds, ensuring robust validation.
6. The optimal model is selected based on the highest average AUC score across the 5 folds
7. The final year-specific model is retrained on the entire training set and evaluated on the held-out test set.

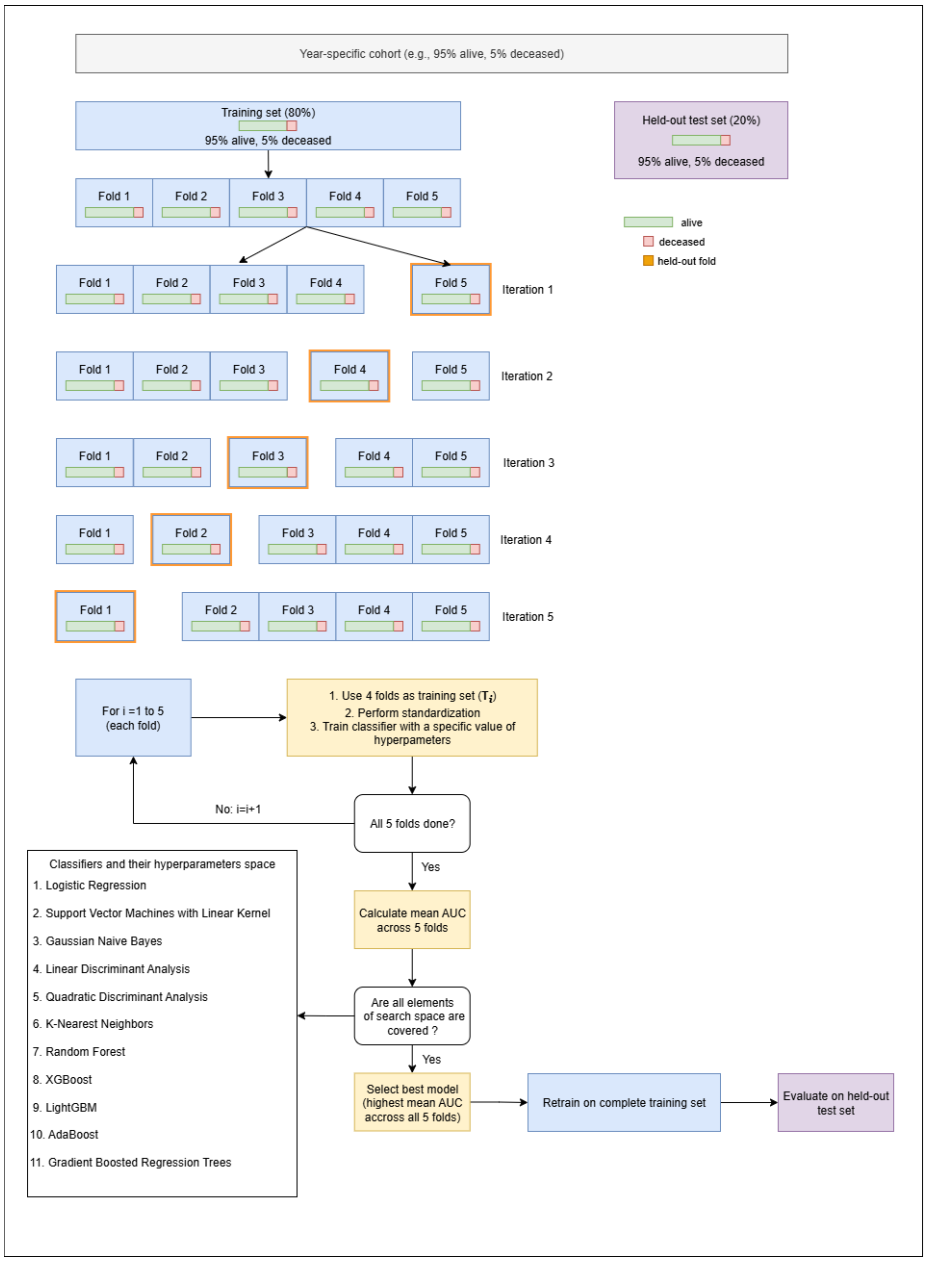

Figure 2. Stratified 5-fold Cross-Validation

To mitigate overoptimism associated with the use of traditional accuracy as the primary performance metric in the presence of class imbalance, we report a range of performance metrics, including precision, specificity, sensitivity, balanced accuracy (BA), geometric mean of sensitivity and specificity (G-mean) and AUC. This comprehensive evaluation provides a comprehensive picture of the model performance, particularly when class imbalance is present.

picture of the model performance, particularly when class imbalance is present.

Explainability via SHAP Analysis

Understanding the underlying decision processes of ML models is critical in healthcare applications. To address this, we employ SHapley Additive exPlanations (SHAP) [21] to assess the contribution of each feature to model predictions. SHAP analysis achieves two primary objectives:

1. **Feature Importance:** assess the contribution of each predictor to the model's output.
2. **Directional Impact**: understand whether a feature increases or decreases mortality risk.

A SHAP value can be either positive or negative, indicating a corresponding positive or negative contribution to the model's prediction. In our case, a positive SHAP value for a predictor indicates that the predictor contributes to a higher probability of one-year mortality, while a negative value contributes toward survival. Given value can push the predicted outcome closer to 1 or 0, which indicates a higher or lower probability of

one-year mortality, respectively. Not only does SHAP analysis help quantify the importance of features, but it also shows the direction of their influence on the outcome. This interpretability is crucial in supporting data-driven decision-making and improving communication between clinicians and patients.

Discussion

This is the first ML/AI based study in Kazakhstan as well as in Central Asia, which was conducted using big nationwide administrative healthcare data. The proposed framework was successfully implemented to predict one-year mortality in diabetes mellitus and chronic viral hepatitis patients using large-scale administrative data in Kazakhstan [4, 5]. These disease groups serve as demonstrations, but the framework is designed to be general and adaptable to additional chronic diseases.

The developed models using the proposed framework showed AUC values between 0.74 and 0.80, which are considered 'fair' and approaching 'good' as per the standard diagnostic metrics [22]. These studies indicate both feasibility and robustness of our approach. Importantly, the proposed framework was helpful in identifying key mortality predictors consistent with prior literature, such as age, sex, disease type and duration of disease, reinforcing the framework's clinical relevance [23-26]. To illustrate this, Figure 3 shows SHAP analysis for the 2019-specific cohort of diabetes patients. The mean absolute SHAP values (Figure 3b) show that age, duration of diabetes and sex are the three top most important predictors (the longer bar shows a more important feature). In Figure 3a, reed dots with positive SHAP values indicate that higher feature values (e.g. older age or longer disease duration) increase the predicted risk of one-year mortality, whereas blue dots with positive SHAP values indicate an inverse relationship.

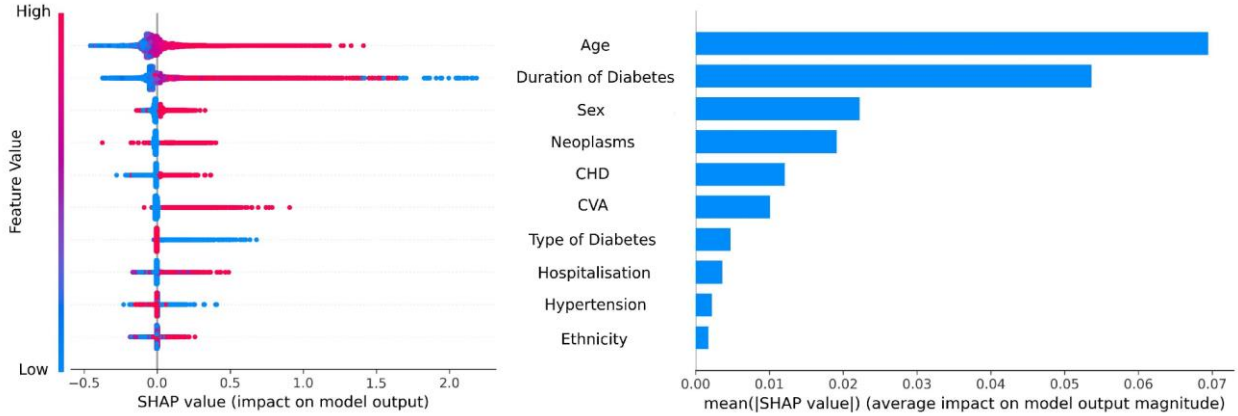

Figure 3. SHAP analysis of 2019-specific cohort of diabetes patients: (a) SHAP summary dot plot for the 2019-specific cohort. (b) The mean absolute SHAP value bar plots for the 2019-specific cohort. Reproduced from [4] under a Creative Commons Attribution 4.0 License.

Comparisons with international studies further highlight the strengths and limitations of our approach. A Chinese study predicting one-year mortality in older patients with coronary artery disease and impaired glucose tolerance or diabetes reported an AUC of 0.83 using GB [27]. In comparison, our study on predicting one-year mortality in patients with diabetes achieved slightly lower but comparable performance (AUC 0.78-0.80), despite being based solely on administrative data without laboratory data or medications use. However, the Chinese study was built on a relatively small set of 451 patients, whereas our model was trained on a larger nationwide cohort of 472,950 patients, offering generalizability.

Similar evidence exists for chronic viral hepatitis. In a study from Sultan Qaboos University Hospital (SQUH), LR models incorporating laboratory markers, genotype, and coinfections reached an AUC of 0.93 for one-year mortality prediction of patients with chronic viral hepatitis C [28]. Our Kazakhstan hepatitis models showed slightly lower results (AUC 0.74-0.80), which is expected given the absence of laboratory and treatment data. Similar to the Chinese study on diabetes, the study from SQUH was a single-center study with 702 patients, whereas our study on hepatitis was developed using large-scale administrative data, enhancing generalizability.

Limitations

This methodological note has several limitations. Results suggest that augmenting administrative data with laboratory measures and treatment information could potentially improve predictive performance. However, augmenting administrative data by laboratory data and clinical notes could introduce new statistical challenges due to high-dimensionality of data [11]. Therefore, the utility of appropriate feature selection techniques would seem crucial to mitigate those challenges. Another limitation is that suggested one year prediction model also may mediated and/or affected by unexpected life-threatening events like sudden death, CV-events, injuries and may differ than natural disease progression. Although, we considered the missing data and applied median imputation for numerical variables and mode imputations for categorical data, these simple approaches may not fully capture the underlying data patterns, and more advanced methods, such as multivariate imputation or k-nearest neighbors imputation, could provide greater robustness. Despite these limitations, the framework itself is designed to be scalable, reproducible, and adaptable, while its performance will need to be confirmed in enriched datasets across additional chronic diseases and diverse populations beyond Kazakhstan.

Conclusion

We propose a scalable and adaptable framework for predicting one-year mortality in chronic disease patients using large-scale administrative data. This approach introduces subcohort definition, model development, and comprehensive performance evaluation, ensuring both methodological robustness and clinical relevance. The inclusion of explainability via SHAP analysis helps healthcare professionals to understand not only which factors influence predictions but also the direction of their impact. Applied to real-world datasets in Kazakhstan, the framework achieved fair-to-good predictive performance, demonstrating its feasibility and reliability in practical settings.

While the framework performed well with administrative data alone, its design allows for integration with enriched datasets, such as laboratory results and clinical notes, which could potentially improve predictive accuracy. Future applications should incorporate feature selection techniques when handling high-dimensional data to maintain computational efficiency and generalizability. In addition, more advanced imputation techniques for handling missing data need to be considered in the future. Lastly, country-specific data quality highlights the need for external validation and application across diverse populations and disease groups. Overall, this methodology provides healthcare systems with a practical and interpretable tool for early mortality risk identification, supporting better-informed clinical decisions and targeted interventions.

Acknowledgements

Author Contributions: Conceptualization, I. A., A. A., and A. G.; methodology, I. A., A. A., T. S., T. A., and A. G.; validation, T. M. and A. O.; writing – original draft preparation, I. A. and A. A.; writing – review and editing, T. S., T. A, T. M., and A. O.; supervision, A. G. All authors have read and agreed to the published version of the manuscript.

Disclosures: There is no conflict of interest for all authors.

Funding: This study was conducted under the grant support from MSHE and under the consortium with Khoja Akhmet Yassawi International Kazakh-Turkish University, Kazakhstan (Grant title: Development of innovative technologies and creation of modern infrastructure for the sustainable development of the South Kazakhstan region. Grant number: BR24992814).

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